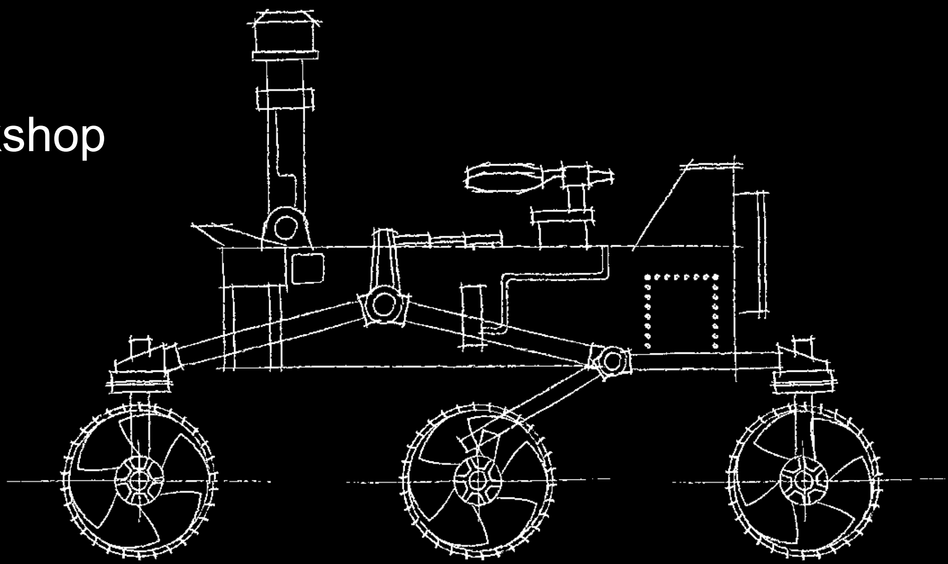
Jet Propulsion Laboratory
California Institute of Technology

Mars 2020 Entry, Descent, and Landing System Overview

11th International Planetary Probe Workshop
Pasadena, CA, USA
June 2014

Allen Chen, Erisa Hines, Richard Otero,
Aaron Stehura, Gregorio Villar

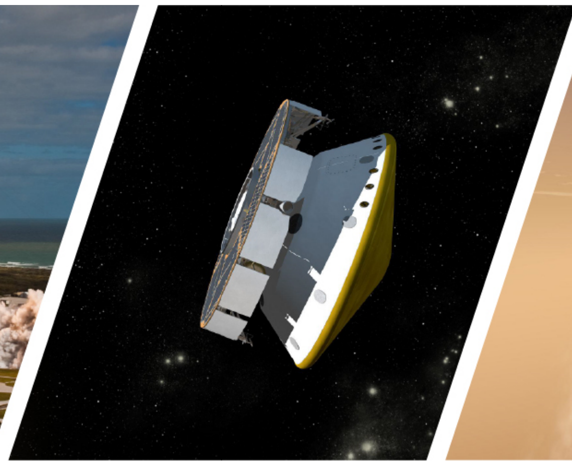


Mars 2020 Project

Mars 2020 Mission Overview

LAUNCH

- Atlas V 541 Class Rocket
- Period: Jul-Aug 2020

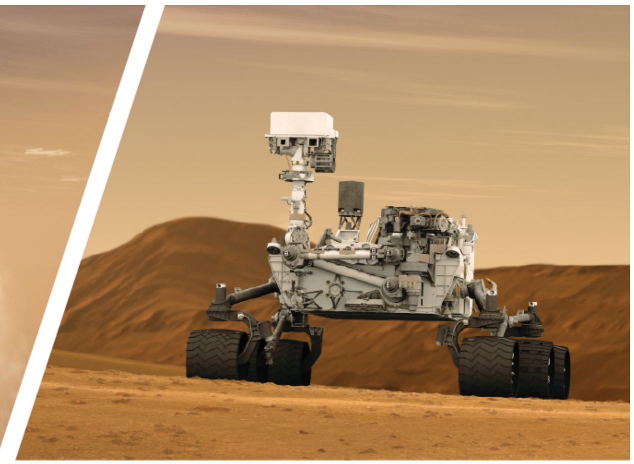


CRUISE/APPROACH

- 7.5 month cruise
- Arrive Feb 2021

ENTRY, DESCENT & LANDING

- MSL EDL System: guided entry, powered descent, and sky crane
- 25 x 20 km landing ellipse
- Access to landing sites ±30° latitude, ≤ 0.5 km elevation
- ~950 kg rover



SURFACE MISSION

- Prime mission of one Mars year
- 20 km traverse distance capability
- Seeking signs of past life
- Returnable cache of samples
- Prepare for human exploration of Mars

Mars 2020 EDL Overview

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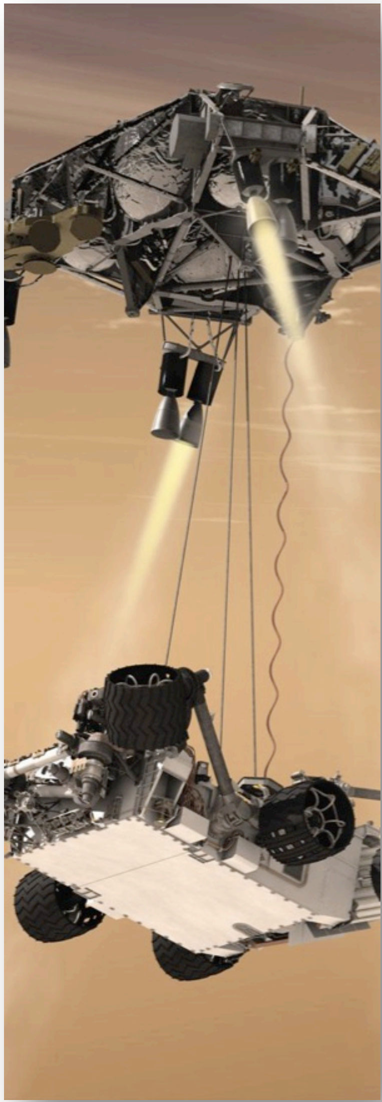
Mars 2020 Project



Mars 2020 EDL System

Goal: Deliver ~950kg rover safely to the surface of Mars

MSL Heritage Design: Guided Entry, Powered Descent, & Sky Crane

The Essentials

Mars Entry:
February 2021

Landing Ellipse:
25 x 20 km

Landing Sites:
± 30° latitude
≤ 0.5 km MOLA

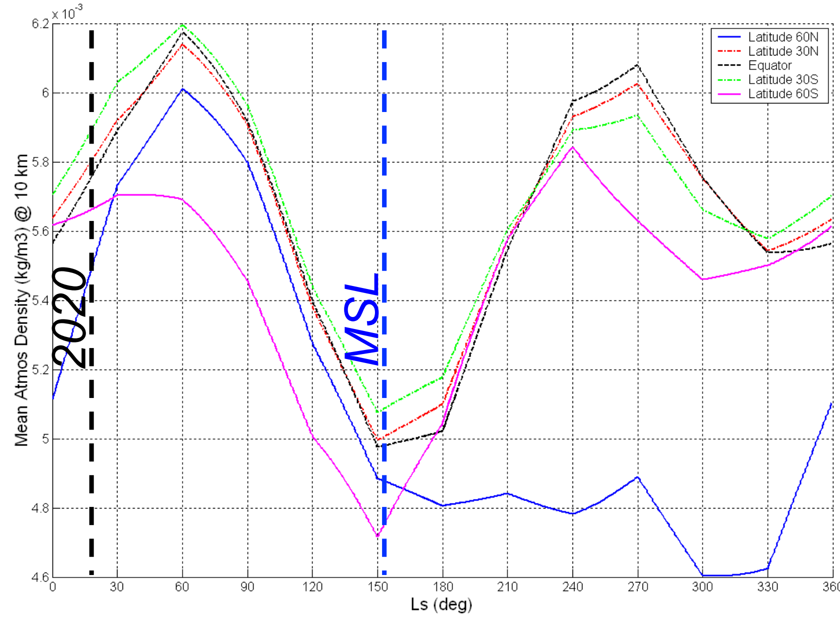
EDL Modifications

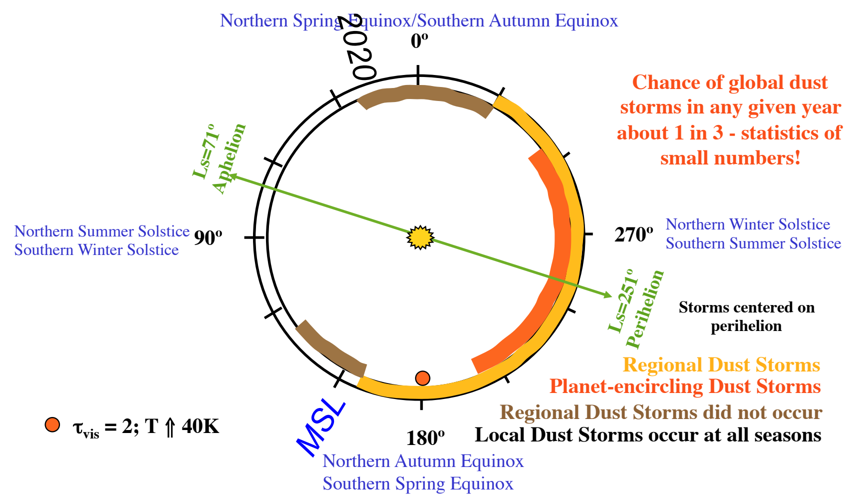
Possible Rationale for Changes:

- Tune for 2020 opportunity
- Respond to MSL issues
- Accommodate new, mission-enabling technologies

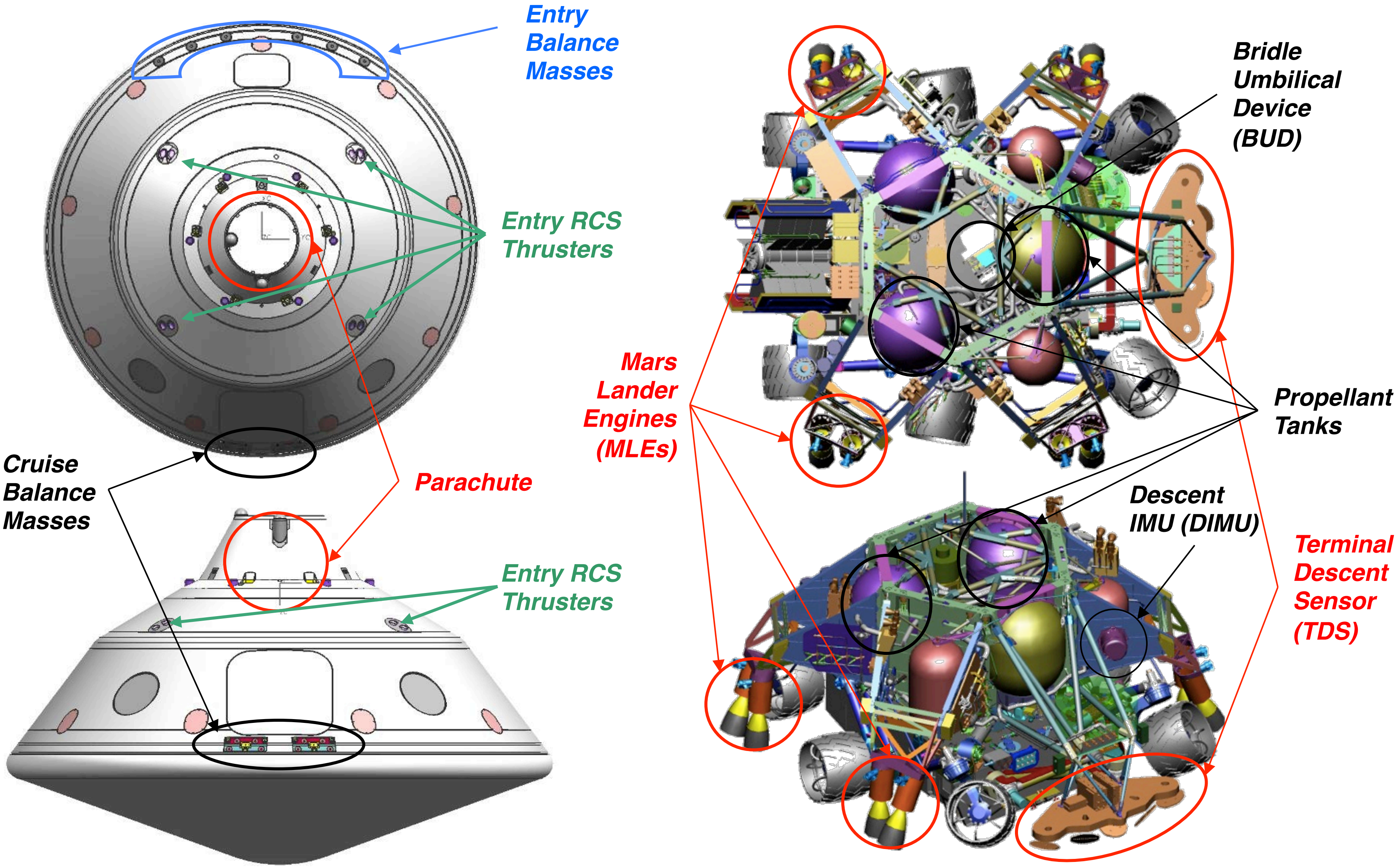
2020 Launch Opportunity

- **Pressure cycle very favorable for 2020**
  - Mars orbit eccentricity transfers CO_2 from polar caps to atmosphere
  - Atmosphere significantly more dense compared to MSL opportunity
  - Low risk of dust events
- **More dense = capability to land safely at higher elevations**
- **2020 atmosphere provides *significant "no cost" improvements* to landing elevation for same landed mass**
  - Higher altitude capability
  - More propellant margin
- **EDL timeline could be extended by ~30 seconds as a result of this opportunity**





Key EDL Hardware



EDL Timeline (with MSL Performance)

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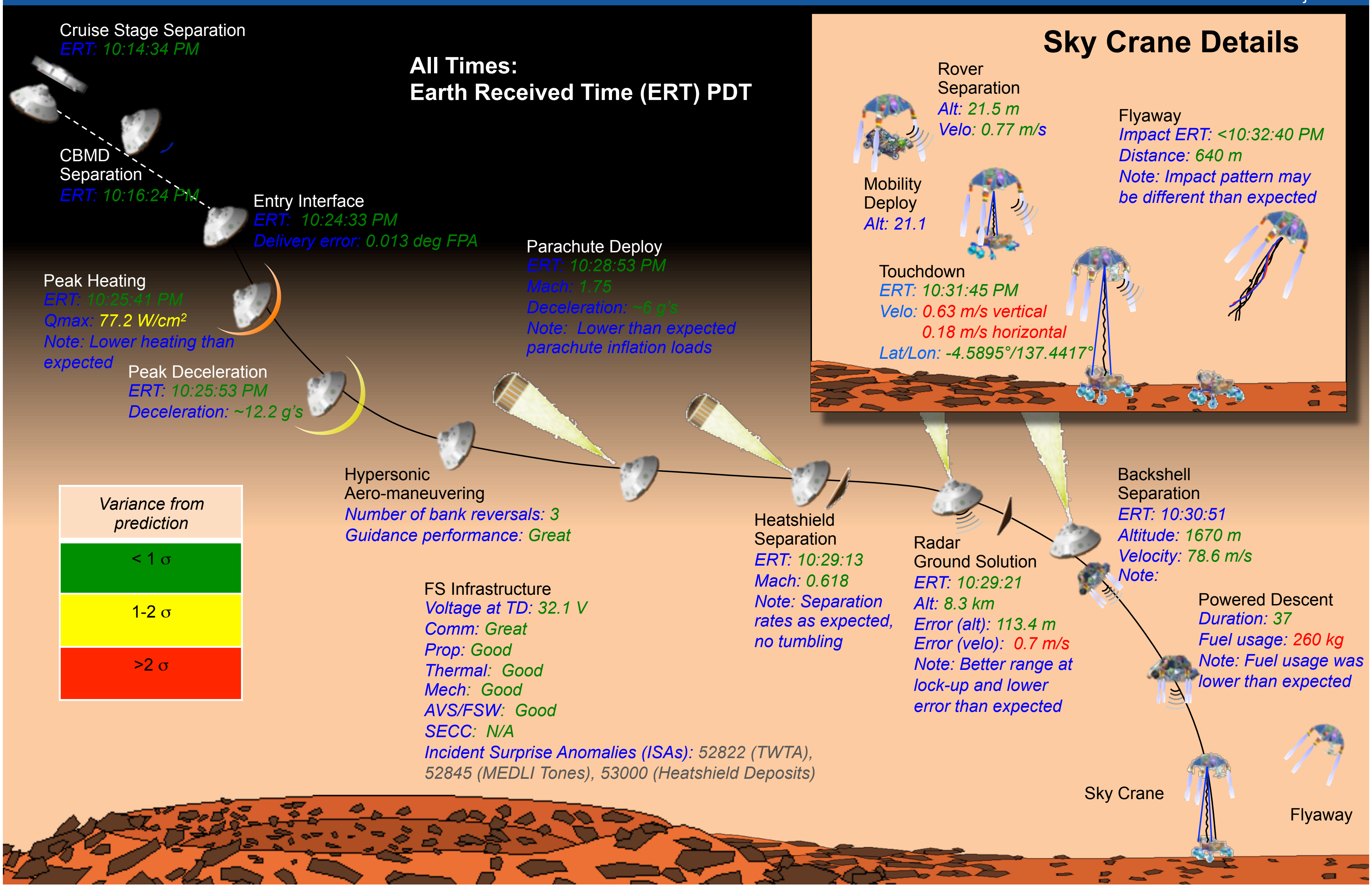

MSL EDL Issues

With Mars 2020 Mitigation Status

Touchdown Velocity Issue

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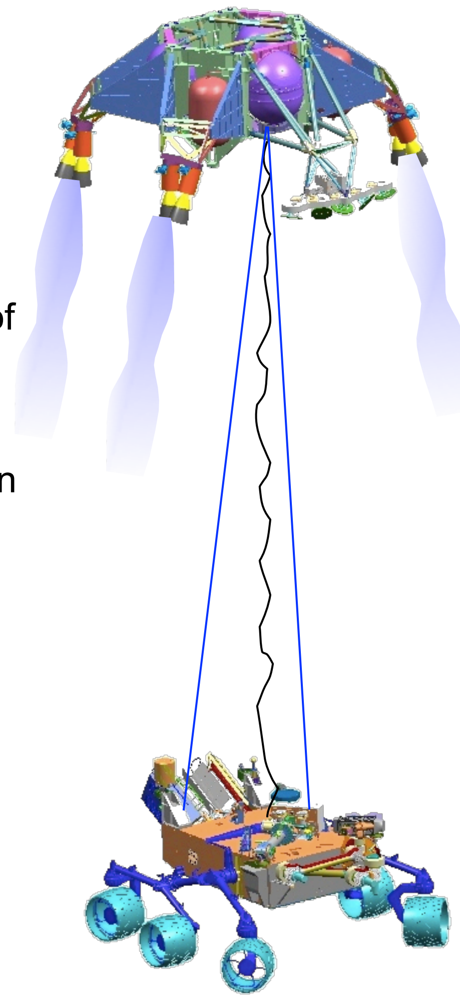
Mars 2020 Project

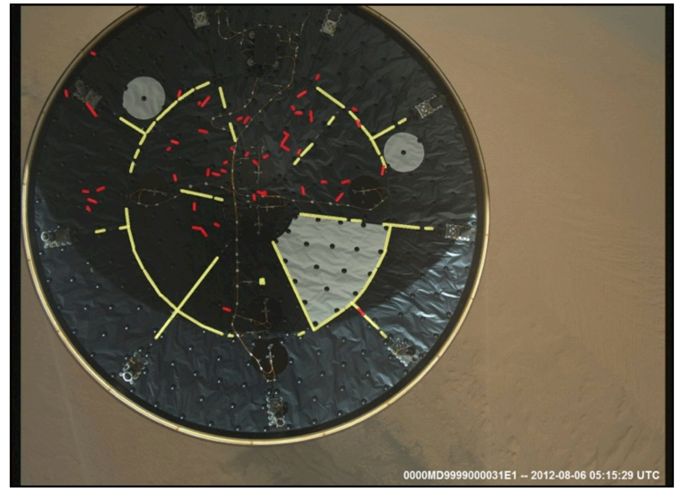
- **Incorrect altitude and velocity estimates during Sky Crane culminated in touchdown conditions outside of predictions**
  - Inaccurate estimation of velocity could result in damage to the rover
- **Root Causes**
  - Local gravity differed from onboard gravity estimate
    - Resulted in lower than expected vertical velocity and contamination of horizontal velocity
  - "Sandy radar" – fast-moving dust picked up by radar
    - Misinterpreted as velocity contribution
    - Increased horizontal velocity error, polluted vertical velocity estimation
- **Possible Mitigations**
  - Add site-specific gravity parameter
  - Filter suspect TDS measurements
  - Tighten attitude initialization
- **Status**
  - Site-specific gravity parameter implemented in EDL/GNC FSW
  - High fidelity gravity maps in development
  - Augmenting TDS model for additional sandy radar effects and studying nav filter tuning strategies
  - Tighter attitude initialization requirement imminent



Heatshield Deposits

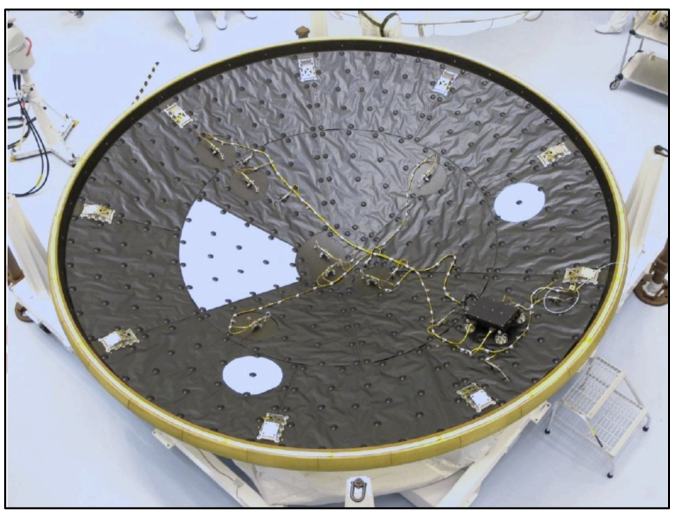
White "ice" spotted on the heatshield

@ Mars (images courtesy of MARDI)



Yellow	=	affixed deposits
Red	=	dislodged deposits

ATLO Pre-Mate



Working Theory

- By-products of outgassing deposited via vacuum deposition
- White Material = H_2O + Organic Volatiles

Other Issues

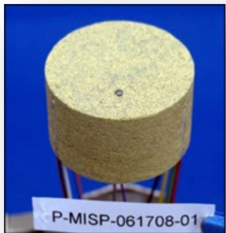
Issue	Description	Status
Debris on rover	Debris flux onto/around rover greater than design intent	• Identified preliminary list of items that might be susceptible to the debris • Plan to characterize susceptible items and materials • Efforts to improve plume/ground interaction modeling are ongoing
TWTA over-current trip	TWTA discretes "tripped" during EDL, sometime after heat shield separation (uncorrelated with dynamic events)	• Investigation in progress with vendor • Likely partial mitigation includes changing internal fault protection to use a "warm reset" to reduce cycle time
Long-Term Backshell Recontact	Uncertainty in landing site winds and parachute dynamics increases long-term recontact risk. Trade space for risk reduction includes: • Larger divert • Site-specific divert logic tuning • Tweak to current divert logic	• Current logic performed well on MSL • Taking advantage of multi-point divert analyses to investigate risk reduction • No other independent analyses planned at this time
Incorrect DIMU origin parameters	The EDL GN&C nav filter parameters specified the location of the origin of the DIMU frame incorrectly (DIMU chassis origin vs. Internal Navigation Reference Point). Addressed just prior to MSL landing.	• Parameter update made on MSL is default on Mars 2020
MLE stiction	The torque/current required to begin motion of the pintle in the TVA was greater in some flight units than in development units	• Vendor disassembled flight spare unit and discovered incorrect lubricant was used • Correct lubricant will be used for Mars 2020

EDL Changes

Mars 2020 vs. MSL

Mars EDL Instrumentation (MEDLI2)

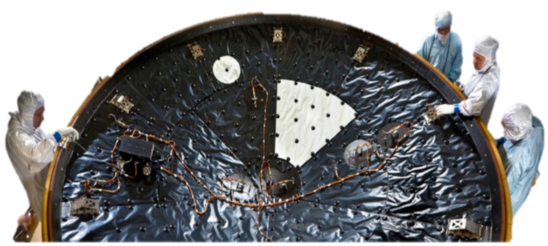
Baselined



MEDLI Instrumented Sensor Plug (MISP)


Mars Entry Atmospheric Data System (MEADS)


Sensor Support Electronics (SSE)



Item	MSL	Mars 2020
Sensor Support Electronics (SSE) Box	1	1
Heatshield: Pressure Transducers	7	7
Heatshield: Thermal Plugs	7	11
Backshell: Pressure Transducers	**0**	**1**
Backshell: Thermal Plugs	**0**	**9**

MSL

- **Gathered engineering data during entry and descent**
  - Aerothermal, aerodynamic, and thermal protection system performance
  - Atmospheric density and winds
- **Findings**
  - Able to reduce required aerothermal environment and TPS design margins for future missions
  - Improved reconstruction of guided hypersonic entry
  - Demonstrated robust and reliable flight instrumentation for planetary EDL
  - Provided near-real time data for fault reconstruction

Mars 2020

- **Improve understanding of**
  - TPS temperature gradients
  - Drag during supersonic deceleration
  - Winds impact on landing accuracy during heading alignment
- **Observe backshell environment and backshell TPS response**
- **Measure backshell contribution to drag**

Range Trigger

Not Baselined

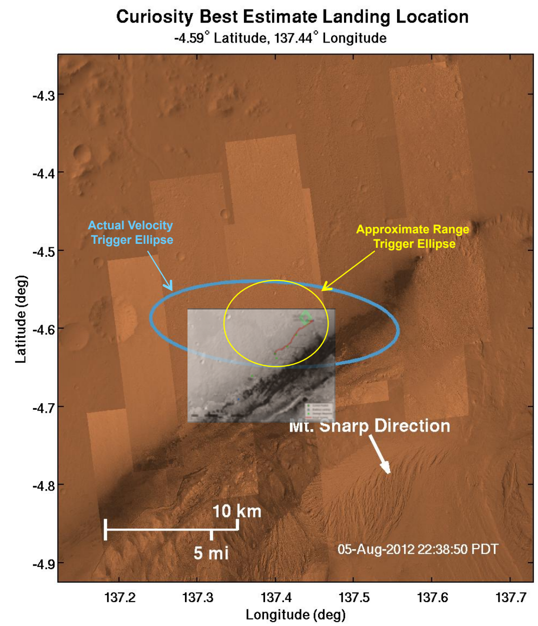
- **Range trigger deploys the parachute based on navigated range instead of navigated velocity**
  - No new hardware is required
  - Simple parachute trigger logic change in EDL Flight Software

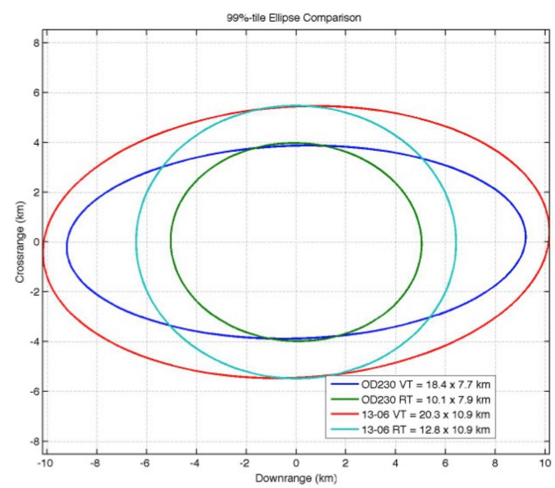
- **Using range trigger can significantly shrink the landing ellipse**
  - Conservatively shrinks,
    - From 25 km x 20 km
    - To 18 km x 14 km
  - ~50% reduction in ellipse area
  - ~8 km reduction in ellipse length

- **Key benefits:**
  - Makes previously inaccessible landing sites accessible
  - Could save ~1 Earth year of driving
  - Bonus: makes the TRN job easier (see next slide)

- **Magnitude of the improvement depends on landing site wind uncertainty and site elevation**

- **Range trigger is not a new idea – it's actually a very old idea that we couldn't adopt on MSL because we were chasing altitude performance**





Terrain Relative Navigation (TRN)

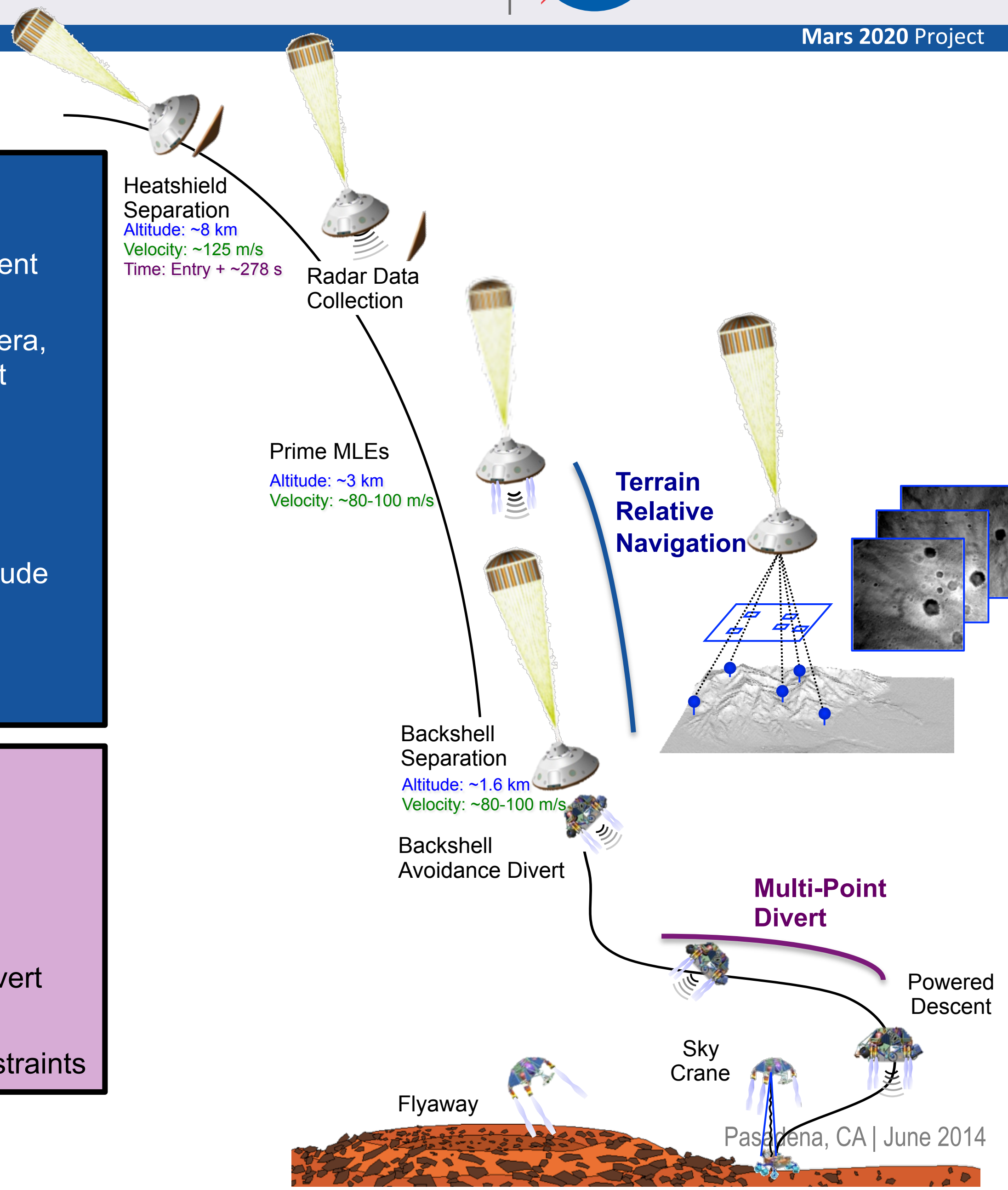
Not Baselined

Terrain Relative Navigation (TRN)

- Works by taking images during parachute descent and matching them to an onboard map
  - Uses a dedicated compute element, camera, and (maybe) an inertial measurement unit
  - Yields a position solution and validity
- Performs terrain relative navigation while the spacecraft is priming the descent engines
  - Operating during priming imposes no altitude "cost"
- Executed by the Lander Vision System (LVS)

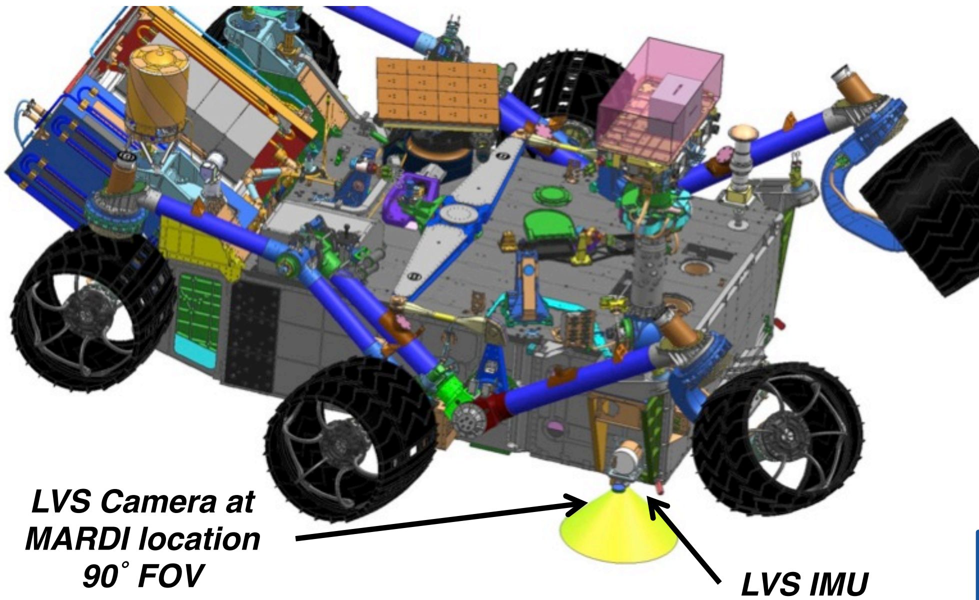
Multi-Point Divert

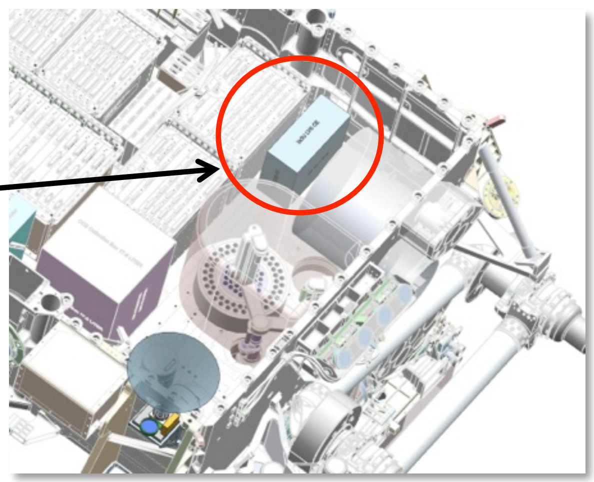
- Uses position solution and list of safe landing locations to select a landing target
- Augments original MSL backshell avoidance divert
- Lives within MSL fuel and control authority constraints



LVS Accommodation

Not Baselined





EDL GNC

Initial State
position, velocity, attitude

State Correction
position, velocity, attitude, validity

Flight Processor

Virtex 5 FPGA

LVS Compute Element

28VDC

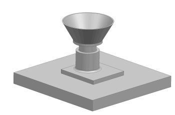
LVS IMU

LVS Camera

rover

accel, angular rates

grayscale image



TRN: *Preliminary* Landing Site Access Results

Partial List of SDT Suggested Landing Sites	Baseline (No TRN)	TRN with 40 m Accuracy	TRN with 60 m Accuracy
NE Syrtis Major	87.0%	99.5%	98.6%
E Margaritifer	87.8%	98.6%	97.1%
Nili Fossae*	95.5%	99.7%	99.4%
Ismenius Cavus	81.6%	94.2%	92.3%
Holden Crater Land-On Target*	96.1%	99.8%	99.6%

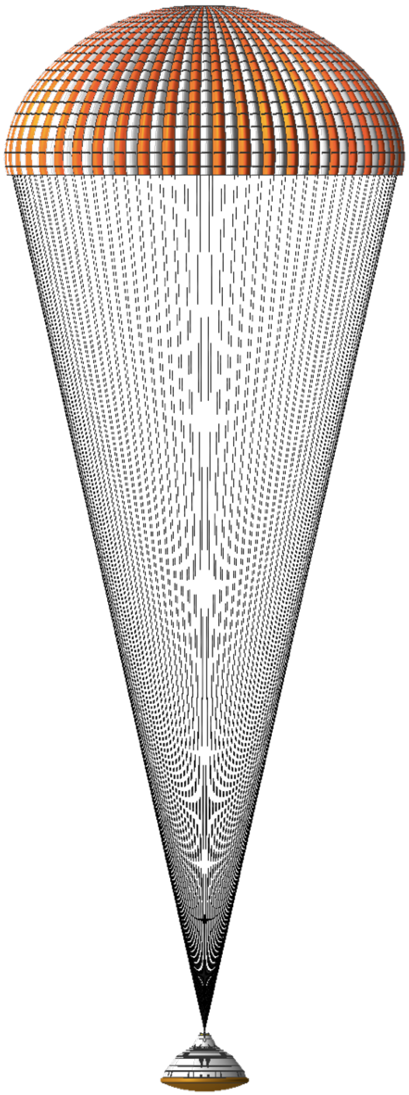
* Assumes a 14x16 km range trigger ellipse at touchdown

- **TRN yields significant improvement in likelihood of safe landing**
  - Maximum site elevation for TRN capability: approximately -1.0 km MOLA
  - Magnitude of improvement higher with better localization accuracy
  - Accuracy worse than 60 m greatly diminishes value of TRN

- **For comparison: At time of selection, MSL final four landing site candidates all ~99% safe with respect to landing hazards**

LDSD-like Parachute

Not Baselined; Unlikely



- **Higher Mach deployment = Increased altitude margin**
  - Landing site requirements (at this time) do not force us to look for increased altitude margin
- **Minimal work to qualify for Mars 2020**
  - May require a development test series
  - Leverage LDSD qualification testing
- **Mars 2020 will decide after the LDSD test program is completed in June 2015**
- **Possible rationale for LDSD chute infusion**
  - If need arises for altitude performance beyond MSL capability (unlikely)
  - As a directed technology demonstration (unlikely)

Landing Site Selection Status

Landing Site Selection

Landing Site Workshop 1

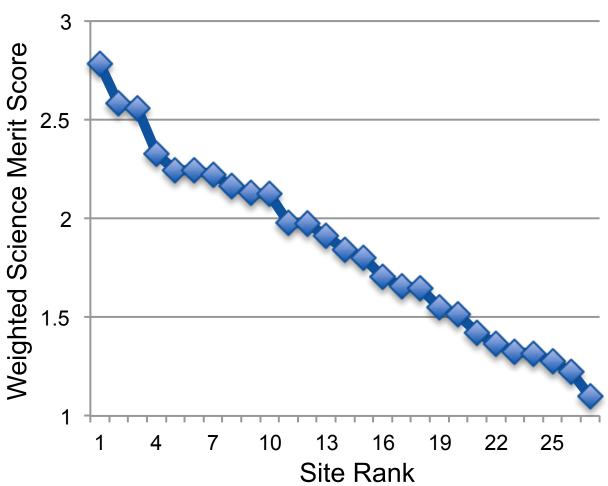
- Took place May 2014 in Arlington, VA
- End result: 27 sites ranked by scientific merit
- Top 3 sites are separated from the rest
- NE Syrtis is the clear frontrunner
- 4 of the top 10 sites are located in the Syrtis Major region
- Elevations and latitudes vary relatively widely
- 2 of the 4 MSL finalist sites are in the top 10
  - Likely to be easily certifiable due to existence of high-quality terrain data products and previous analysis

Current Status

- Assessing need for EDL enhancements to increase landing safety (preliminary pass complete)
- Determining need for additional imaging

The Road Ahead

- Landing Site Workshop 2
  - June 2015, prior to Mars 2020 PDR
  - Desired end result: 8 sites, with 4-5 "selectable" (mitigates potential loss of MRO)
- Workshop 3 (2017) and Workshop 4 (2018)



Rank	Candidate Landing Site	Latitude, Longitude, Elevation (MOLA)	Need for Additional Imaging by Orbiters	Is Site Likely Land On or Go To?	Is Range Trigger Likely Needed for Access?	Does Access Likely Require TRN?
1	NE Syrtis	16.2˚N, 76.6˚E, -2.15 km	Low (High for Alternate Ellipse)	Mostly Land On	No	Yes
2	Nili Fossae Trough	21.0˚N, 74.5˚E, -0.61 km	Low	Mostly Go To	Yes	Maybe
3	Nili Fossae Carbonates	21.7˚N, 78.7˚E, -1.50 km	Low	Land On	No	Yes
4	Jezero Crater Delta	18.4˚N, 77.6˚E, -2.50 km	Low	Partially Go To	No	Yes, to avoid rocks
5	Holden Crater	-26.4˚N, 325.2˚E, -2.14 km	Low	Go to without TRN; Land on with TRN	No	No for Go To; Yes for Land On
6	McLaughlin Crater	21.9˚N, 337.7˚E, -5.05 km	Medium	Mostly Land On	?	?
7	Southwest Melas Basin	-9.8˚N, 283.6˚E, -1.85 km	Low	Land On	Yes	?
8	Mawrth Vallis, MSL Site	24.0˚N, 341.0˚E, -2.29 km	Low	Land On	No	No
9	East Margaritifer Chloride	-5.6˚N, 353.5˚E, -1.25 km	Low	Land On	No	Yes
10	Oyama Crater, clay layers	23.4˚N, 340.2˚E, -3.89 km	Medium	Land On	No	No

Summary & Conclusions

- MSL EDL design will remain largely intact
- 2020 is a very favorable launch opportunity
- MSL EDL issues are being mitigated
- MEDLI2 has been baselined
- Other augmentations are being explored

Questions?

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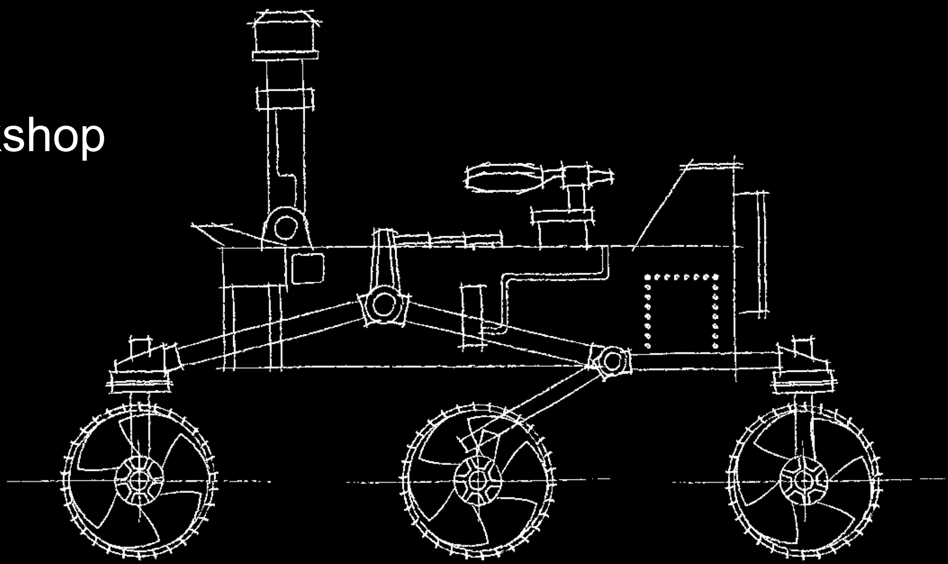

Mars 2020 Project

Backup

Mars 2020 Entry, Descent, and Landing System Overview.

Allen Chen[1], Erisa Hines[1], Richard Otero[1], Aaron Stehura[1], and Gregorio Villar[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109.

Abstract

In December 2012, NASA announced it would pursue a Mars rover for the 2020 launch opportunity, designed to search for signs of past life and collect samples for possible future return to Earth. Referred to as Mars 2020 (M2020), it would be a follow-on to the Mars Science Laboratory (MSL) mission, heavily leveraging MSL heritage to reduce cost and schedule risk while accommodating an as-yet-undetermined set of science instruments. M2020's Entry, Descent, and Landing (EDL) system would use the approach successfully pioneered by MSL [1], but a small number of changes are being considered to correct deficiencies, improve performance or demonstrate targeted technologies. This paper presents an overview of the M2020 EDL design and summarizes the status on a series of trade studies investigating proposed changes from the MSL baseline. These possible changes include tuning EDL flight dynamics for the 2020 opportunity, revisiting a number of issues that were discovered during the development, testing, and flight of MSL, and accommodating a variety of prospective EDL technologies. The M2020 payload selection and the first landing site workshop are scheduled for mid-2014 and will provide a better perspective on the necessity of specific improvements to the M2020 EDL system.

References

[1] Ravi Prakash. et al. (2008) *Mars Science Laboratory Entry, Descent, and Landing System Overview,* IEEEAC paper #1531.

Heatshield Deposits

- White material was deposited through a process known as vacuum deposition / "gettering" gradually throughout Cruise

- White material is thought to be by-product of DS/Rover/Aeroshell component outgassing
  - most likely a mix of water and "gooey" organic volatiles (from MLI, paints, coatings, adhesives, etc…)
  - Therefore, frozen volatiles… NOT just water ice

- Vacuum deposition occurs as molecules are outgassed (pressure-effect) or released/ excited from surface (thermal-effect)
  - Molecules then undergo random motion until they are expelled from the Aeroshell or get "trapped" by a surface
  - Surface will trap molecule if it can extract enough energy from the molecule such that it will not leave the surface (i.e. if the surface is really cold)

- Vacuum deposition is a line-of-sight phenomena
  - The releasing surface usually sees the deposition surface (w. 2nd order exception for "reflected" molecules)

- Vacuum deposition has been known to occur at ~150K (-123C) on past spacecraft